Short-rotation poplar: a harvesting trial

Bruce R. Hartsough
Bryce J. Stokes
Charles Kaiser

Abstract

A study of components of two systems for harvesting short-rotation poplar (*Populus* spp.), one utilizing a tracked skidder and the other based on cable yarding, was carried out in Oregon. The terrain was flat, and dry enough to allow the use of tractive equipment. Stump-to-truck pulp chip cost estimates were \$33/bone dry ton (BDT) and \$57/BDT for the observed skidder and yarder systems, respectively, and \$41/BDT for a hypothetical optimized yarder-based system. The skidder system appeared to be a viable alternative for producing pulp chips during dry weather. Several problems need to be addressed to make the yarding system physically and economically feasible. If trees were prebunched, the production rate for the yarder would be half that of the flail delimber/debarker. Some of the crop trees used as intermediate supports broke while yarding unbunched turns; stronger supports would be needed to handle the larger prebunched turns.

Over the past few decades, many groups have evaluated short-rotation woody biomass plantations for the production of energy feedstock (1,3,10-12,15). Most analyses concluded that the costs of alternative sources of energy would have to increase in order to make energy plantations competitive. In the last few years, attention has shifted to the use of short-rotation plantations as a source of pulp furnish, with residues being utilized for fuel. Several companies have established trial or operational-scale plantations of poplar (*Populus* spp.) or *Eucalyptus* spp. in states or provinces along the West Coast.

Several empirical studies of harvesting systems for short-rotation plantations have been carried out (4,8,13,16). The empirical studies have addressed the use of short-rotation biomass for energy, not pulp, and have dealt with smaller trees than those being grown for pulp production. While the harvesting of pulp furnish-sized short-rotation trees has been simulated (7), little hard data exist.

Pulp material must be delimbed and debarked. Chain flailing is becoming the preferred means for processing small trees for pulp furnish because of multiple-stem handling capability and the feasibility of on-site processing and chipping, which results in full-capacity truckloads. Studies of flails and other equipment that could be applied in short-rotation plantations have been reported (14), but they considered either longer rotation conifers or hardwoods from natural stands. Clonal stands of short-rotation poplar differ from natural stands because of the uniformity of tree size; they also have different wood and bark physical properties than either conifers or other species of hardwoods. These factors can affect delimbing and debarking effectiveness, and production rates for all harvesting activities.

This study evaluated one of the first harvesting operations of short-rotation hardwoods for pulp production in North America.

Study conditions

Harvesting trials were conducted by James River Corporation on a planting of hybrid poplar near

The authors are, respectively, Associate Professor, Biol. and Agri. Engineering Dept., Univ. of California, Davis, CA 95616; Project Leader, USDA Forest Serv., Southern Forest Expt. Sta., Auburn Univ., AL 36840; and Forest Engineer, James River Corp., Lower Columbia River Fiber Farm, Clatskanie, OR 97106. This paper was received for publication in April 1992.

Forest Prod. J. 42(10):59-64.

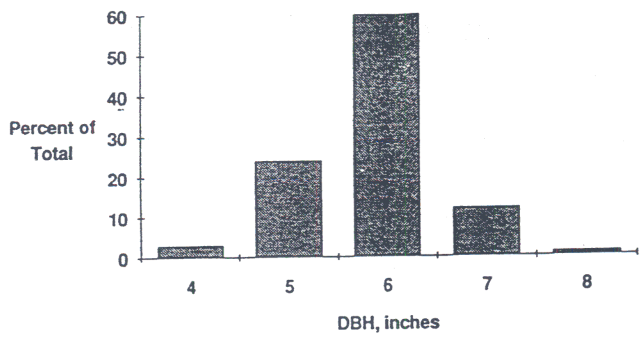

Figure 1. — Tree diameter distribution.

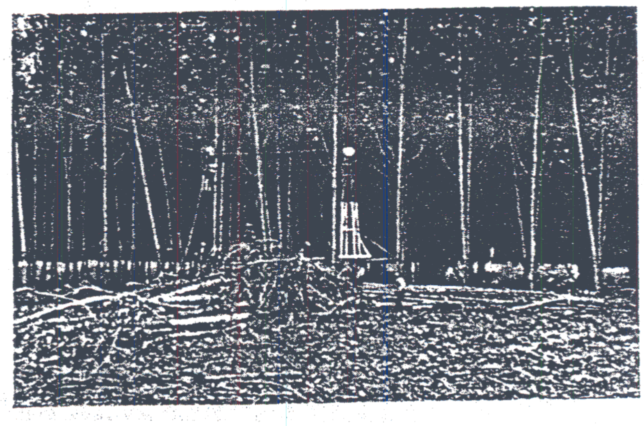
Figure 2. — Cable yarder and cold-decked trees.

Clatskanie, Oreg. They were studied during the period July 8 to 11, 1990. The area was flat alluvial ground adjacent to the Columbia River in diked agricultural areas, and had no obstacles. The soil surface was dry during the study period but could be under standing water at some times of the year.

Figure 1 displays the distribution of diameters for a random sample of 89 interior trees. The average diameter at breast height (DBH) was 5.8 inches. We derived the green and dry weights of chips per tree from the net weights of the chip vans, counts of trees processed into the vans, and moisture samples for the chips. We then used proprietary biomass equations that gave the ratio of whole tree/clean bole to estimate whole tree weights. With this approach, the average total aboveground tree weight was calculated to be 234 green pounds or 120 dry pounds.

The study conditions differed from those in previous studies in three ways: 1) species; 2) uniformity of tree size; and 3) the flat alluvial site, which was subject to flooding during a large part of the year. This last factor motivated James River Corporation to test systems that might be applicable during the wet season.

Equipment and systems

Two harvesting systems were studied: one used tractive skidding and the other a cable yarder. All the trees from the test unit were eventually delimbed, debarked, and chipped for pulp furnish. The residues were left on the site because facilities for utilizing biomass fuel were not yet in place.

Skidder system

A Morbell Mark V feller buncher with a 14-inch accumulating shear head bunched whole trees to be skidded by a Caterpillar D4H Custom Skidder to a flail and chipper. The trees were felled 1 to 2 weeks before chipping, so there were no interactive delays between the felling and later activities. Most trees were felled and bunched before the data-collection period, so felling and bunching was not studied in detail.

The skidder was equipped with a fixed Esco 12F grapple. Trees were skidded hot to the landing where a Case 880 knuckleboom loader fed them butt-first into a Peterson Pacific 4800 flail debarker. The delimbed and debarked boles continued onto the infeed deck of a Morbark Model 22 chipper equipped with a knuckleboom loader.

The flail had been modified to improve its performance on the small, relatively brittle poplar. Vertical pipe was welded to the front of the machine to narrow the infeed opening. The top infeed roller was lowered to reduce the minimum opening to a height of 4 inches. The control pendant for the debarker was mounted in the loader cab so the feed roll could be raised by the loader operator. Flail chains consisted of strands of 12 links of 3/8-inch chain, 2 strands per hole in the flail drum.

The on-site crew included the feller buncher operator, skidder operator, loader operator, chipper operator, and a foreman who was present at this operation approximately half the time. All activities in this system were studied.

Yarder system

The second system was recommended by a knowledgeable consultant as one of the best possible for harvesting during the wet season, when soft soils might restrict the use of tractive equipment. It utilized a Koller K300 skyline yarder (Fig. 2). Trees were felled with a chain saw in advance of yarding and prior to the study period, with tops oriented away from the landing. These trees were purposely not prebunched to simulate the situation where no tractive equipment could be used.

An operational system would include the activities downstream of yarding, but these were not in place during the study. Yarded trees were cold-decked at the yarder.

The yarder, equipped with a 5/8-inch skyline, 3/8-inch mainline, and 5/16-inch haulback, utilized a Koller manual slackpulling carriage. A single strip, 600 feet long and 120 feet wide, was yarded from a single corridor in the center of the strip. The skyline

TABLE 1. — *Skidding time study results.*

Variable	Mean	SD[a]	n
Time/turn (min.)			
Travel empty	1.049	0.476	41
Position and grapple	0.533	0.402	41
Travel loaded	1.312	0.567	41
Unload	0.070	0.142	41
Blade residue	0.188	0.523	41
Distance (ft.)			
Empty	448	229	40
Loaded	448	227	40
Stems/turn	15.17	4.26	41

[a] SD = standard deviation.

was supported at 340 feet from the yarder by an "M" intermediate support through two standing trees, and at 620 feet by a tailblock in a 7-inch-DBH tree. The skyline was anchored to two 6-inch tailholds via a block arrangement. The support jack was 14 feet above the ground, the tailblock was at 18 feet.

Two people, an operator/chaser and a choker setter, crewed the yarder. The choker setter preset three chokers when yarding within 500 feet of the tower. It was very difficult to pull slack beyond this distance, so the haulback was rigged to the dropline to pull slack. Chokers were not preset at the longer distances because they could not easily be removed from or restrung on the taut mainline/dropline.

Data collection

Time-motion study was used to collect production cycle data for the skidding, yarding, and landing (flailing and chipping) activities. A target of 40 observations per activity was determined in advance, to achieve a 95 percent confidence interval on total cycle time of within plus or minus 10 percent of the mean, assuming a coefficient of variation of 30 percent. Although delays were recorded, only the productive cycle results were analyzed because the study was too short for delay percentages to be meaningful.

The number of stems per cycle was recorded for each of the activities, and DBHs were recorded for the yarding activities.

The number of stems required to fill each of five chip vans was also recorded. Each van was weighed, and moisture contents and chip classifications were estimated from samples taken from the vans. A Rader Model CC2000 chip classifier was used.

Proprietary biomass prediction equations and cruise data were used to estimate the total amount of biomass on the harvest unit. An estimate of the total amount of residues available for fuel was made by subtracting the total amount of chips delivered to the pulpmill from the total biomass estimate.

Results

Skidding

The skidding cycle was defined as the time per turn. This was divided into five elements: travel empty, position and grapple, travel loaded, unload, and blade residue. The blading of residue away from the flail and chipper was considered an element rather than a delay because it occurred fairly regularly and was a necessary part of the operation. Travel distances were also recorded. The data are summarized in Table 1. Average turn time was 3.15 minutes, or 0.21 minute per stem. Regressions of time versus distance were run for both travel empty and travel loaded:

$$\text{Travel empty (min.)} = 0.124 + 0.00206 \times \text{Distance (ft.)}$$

$$r^2 = 0.96 \qquad F = 834 \qquad n = 40$$

$$\text{Travel loaded (min.)} = 0.223 + 0.00241 \times \text{Distance (ft.)}$$

$$r^2 = 0.91 \qquad F = 408 \qquad n = 40$$

Turn size for the skidder was limited by the area of the grapple opening rather than tractive capacity or power. In most cases, the skidder picked up a single bunch. These had been sized by the feller buncher operator to match the grapple capacity.

Flailing and chipping

Since the flail was the limiting one of the three pieces of equipment at the landing (loader, flail, and chipper), the observed production rate was that of the flail. The activity of the loader feeding the flail was timed. The cycle was defined as the time per swing of the grapple to move trees from the deck to the flail infeed, and included waiting time while the flail was processing the trees.

The mean time per swing was 0.81 minute (standard deviation (SD) = 0.26 min., $n = 319$), and mean stems per swing was 4.1 (SD = 1.5, $n = 319$). Although stem diameters were not recorded for the flailing operation, it was apparent that the loader operator picked up more trees per swing when the trees were smaller. Because of the difficulty of orienting multiple stems, time per swing increased significantly with the number of stems, as was indicated by the regression result:

$$\text{Time per swing (min.)} = 0.495 + 0.0765 \times \text{Stems per swing}$$

$$r^2 = 0.21 \qquad F = 86 \qquad n = 319$$

Two factors limited the production rate of the flail. The throughput rate had to be held down to keep bark content to acceptable levels (< 1%). The loader operator commented that, for the small poplar, he also waited longer between feeding stems because the stems in the flail tended to break if another bunch was placed on top of them.

The crew checked the flail chains after every load, and replaced or rotated chains as needed. The foreman indicated that a set of chains lasted an average of 10 loads.

The debarked poplar was easy to chip and caused little wear on the chipper knives. The set of knives installed at the beginning of the harvest trial was still performing satisfactorily after 30 van loads.

Cable yarding

The yarding cycle was defined as the time per turn. This was divided into four elements: outhaul, hook, inhaul, and chase. In addition, a delay related to the size of the deck occurred frequently because no machine was available to swing turns away from the yarder. These times were reported to indicate the importance of maintaining a clear chute on this flat terrain when using a yarder with a short tower. It was excluded from the production analysis because the delay could be eliminated by using a swing device to move turns from the chute. The data are summarized in Table 2. Average time per turn was 5.08 minutes, or 1.37 minutes per stem. Regressions of time versus distance were run for both outhaul and inhaul:

$$\text{Outhaul (min.)} = 0.347 + 0.00079 \times \text{Distance (ft.)}$$

$$r^2 = 0.21 \quad F = 12.9 \quad n = 49$$

$$\text{Inhaul (min.)} = 0.353 + 0.00127 \times \text{Distance (ft.)}$$

$$r^2 = 0.41 \quad F = 40.5 \quad n = 58$$

The average load weight was estimated to be about 900 pounds, assuming an average green weight of 234 pounds. During the trial, payloads were limited by the number of chokers and by the strength of the support trees rather than by the capacities of the yarder or lines. One intermediate support tree was broken when a relatively large turn, weighing approximately 1,200 pounds, was yarded over the support jack.

The limiting payload capacity for the yarder and lines on the observed corridor profile was conservatively estimated at 2,000 pounds by using a skyline analysis program (9) with a factor of safety of three on the breaking strength of the lines.

Landing delays occurred when the deck reached a height of approximately 5 feet. At this point, turns could not be lifted over the back of the deck, so they had to be landed behind the first deck. Much of the delay time was spent walking from the yarder to the second deck and back, and using a peavey to roll logs off of the deck. A swing device (an auxilliary winch, small loader, or skidder) would be needed on a production operation to avoid the delays.

TABLE 2. — *Cable yarding time study results.*

Variable	Mean	SD[a]	n
Time/turn (min.)			
Outhaul	0.746	0.193	37
Hook			
Preset	1.931	0.551	25
Not preset	3.497	0.746	13
All turns	2.467	0.972	38
Inhaul	0.992	0.248	37
Chase	0.875	0.240	35
Deck delay (min./turn)	0.543	1.087	39
Skyline distance (ft.)	483	69	39
Stems/turn	3.70	1.02	37
DBH (in.)	5.67	1.11	132

[a] SD = standard deviation.

TABLE 3. — *Cost estimates for system components (1991 dollars).*

Machine	Purchase price	Hourly cost
	($)	($/SH)
Chain saw	500	20
Feller buncher	90,000	35
Skidder	150,000	50
Loader	95,000	36
Flail	140,000	78
Chipper	250,000	81
Yarder	65,000	42
Swing skidder	100,000	39

TABLE 4. — *Production rates for system components.*

Machine	Stems/PH	Maximum stems/SH
Skidder	288	187
Flail	306	199
Yarder-observed	50	40
Yarder-optimized	127	102

Residue, tree weight, and chip classification

Of the total estimated aboveground weight of trees on the test unit, 72 percent was delivered to the pulpmill in chip form. By subtraction, the residues were estimated to be 28 percent of the total weight. A small fraction of the residues were broken off during felling or skidding, but the large majority were left at the landing. These included tops, limbs, and bark removed by the flail; broken pieces that could not be fed into the flail; and sections of bole that broke while being debarked. Breakage had been reduced by the substitution of smaller-than-normal chains, but some loss was still occurring.

The average weight of chips recovered from each tree in the five observed vans was 168 green pounds or 86 dry pounds.

Almost 80 percent of the material delivered to the pulpmill was in the acceptable size range of 2 mm to 45 mm. Bark content averaged 0.6 percent.

System balancing and costs

Replacement purchase price and hourly cost estimates for the equipment, or for currently available replacements, are listed in Table 3. Hourly costs were calculated via the machine rate approach. Key assumptions for the hourly costs included usage of 2,000 scheduled hours (SH) per year, 5-year lives for all equipment except the yarder (10 yr.), 20 percent salvage values, an interest+insurance+tax rate of 15 percent of average investment, and labor costs of $10 per hour plus 50 percent loading. Based on published data (2,5,6), we assumed maximum utilization rates of 80 percent for the yarder and 65 percent for all other equipment. In a complete system, the utilizations for most equipment differ slightly from these rates because we assumed the systems were balanced to the least productive function. Flail hourly costs are high because of the chain costs: $500 per set, with a life of 10 loads per set as reported by the crew foreman.

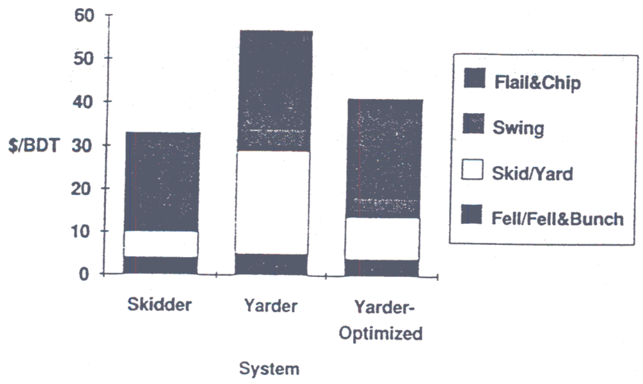

Figure 3. — Stump-to-truck costs for pulp chips.

Skidder system

Table 4 shows that the observed skidder production was slightly less than that of the flail. At maximum utilization rates, skidder productivity would equal that of the flail at an average skid distance of 400 feet (an external distance of 600 to 800 ft., depending on the dimensions of the skidded area). It was assumed that a balanced system would include one tricycle feller buncher, a skidder, loader, flail and chipper, and produce at the flail-limited rate of 199 stems/SH, equivalent to 8.6 BDT of pulp chips/SH.

Total hourly cost for the balanced skidder system is $280/SH. The stump-to-truck cost is then $33/BDT of chips. Costs for system components are displayed in Figure 3.

Yarder system

A setup time of 1 hour per corridor was included for the yarder, assuming a prerigged tailblock and intermediate support.

Observed system.—For trees felled with chainsaws, preset turns, and an average yarding distance of 300 feet (i.e., a 600-ft. corridor), the yarder would produce approximately 40 stems/SH. This is only one-fifth of the production rate of the tractive system as limited by the flail. Trees would have to be cold-decked for later flailing and this could be accomplished at negligible cost by using a small auxilliary winch on the yarder. A small skidder could then swing turns from the cold decks to the flail and chipper. Costs for this two-stage system would be approximately $57/BDT of chips.

Hypothetical optimized system.—If a feller buncher was used to prebunch turns that averaged near the yarder's payload capacity (8 to 9 stems, 2,000 lb. of green weight); if intermediate supports could be built to handle these payloads; and if hook plus chase time was reduced to 2 minutes due to the prebunched turns; then the yarder would produce a maximum of 102 stems/SH, including the effect of time to change roads. This is half of the capacity of the flail. A balanced system would have one feller buncher, two yarders, and the same landing equipment as for the skidder system. A small skidder would also be needed to swing turns from the yarders to the flail. Total cost for this system would be $353/SH, with a flail-limited production rate of 8.6 BDT of chips/SH. Resulting cost would be $41/BDT of chips. But it is not likely that all of these productivity improvements could be made.

Conclusions

Skidder system

The skidder system appears to be a viable alternative for producing pulp chips if soil conditions permit the use of tractive equipment.

The flail was the bottleneck in the system. It might be possible to eliminate the chipper operator, or the loader and loader operator by using a combination flail delimber/debarker/chipper.

Yarder system

Use of a yarder is more problematic. Stump-to-truck costs for the unbunched operation are high. They represent half or more of the market value of chips delivered to a papermill. Adding the costs of growing the trees and transportation leaves little margin for profit. The biggest deficiency of the cable system is the need for two or more yarders to match the productivity of the flail and associated landing equipment. The lack of adequate natural intermediate supports is also a concern. Even under the best possible conditions, i.e., where two yarders could be utilized efficiently together and where payloads averaging 2,000 pounds could be yarded over the supports, stump-to-truck costs for this system would exceed those for the skidder system by approximately 25 percent.

Literature cited

1. Bowersox, T.W. and W.W. Ward. 1976. Economic analysis of a short-rotation fiber production system for hybrid poplar. J. of Forestry 74:750-753.
2. Brinker, R.W., D. Miller, B.J. Stokes, and B.L. Lanford. 1989. Machine rates for selected forest harvesting machines. Circular 296. Alabama Agri. Expt. Sta., Auburn Univ., Ala.
3. Campbell, G.E. 1988. The economics of short-rotation intensive culture in Illinois and the Central States. Forest Res. Rept. 88-12. Dept. of Forestry, Univ. of Illinois at Urbana-Champaign.
4. Curtin, D.T. and P.E. Barnett. 1986. Development of forest harvesting technology: application in short rotation intensive culture (SRIC) woody biomass. Tech. Note B58. Tennessee Valley Authority, Div. Land and Econ. Res., Knoxville, Tenn.
5. Dykstra, D.P. 1975. Production rates and costs for cable, balloon, and helicopter yarding systems in old-growth Douglas-fir. Res. Bull. 18. Forest Res. Lab., School of Forestry, Oregon State Univ., Corvallis, Oreg.
6. ________. 1976. Production rates and costs for yarding by cable, balloon, and helicopter compared for clearcuttings and partial cuttings. Res. Bull. 22. Forest Res. Lab., School of Forestry, Oregon State Univ., Corvallis, Oreg.
7. Golob, T.B. 1986. Analysis of short rotation forest operations. NRCC No. 26014. National Res. Council of Canada, Ottawa, Ont.
8. Hartsough, B.R. and G. Nakamura. 1990. Harvesting Eucalyptus for fuel chips. California Agriculture 44(1):7-8.
9. Oregon State University. 1987. LOGGERPC, Version 1.2. Dept. of Forest Engineering, Corvallis, Oreg.
10. Perlack, R.D. and J.W. Ranney. 1987. Economics of short-rotation intensive culture for the production of wood energy feedstocks. Energy 12(12):1217-1226.

11 Rose, D., K. Ferguson, D.C. Lothner, and J. Zavitkovski. 1981. An economic and energy analysis of poplar intensive cultures in the Lake States. Res. Pap. NC-196. USDA Forest Serv., North Central Forest Expt. Sta., St. Paul, Minn.

12. Standiford, R.B. and F.T. Ledig. 1983. Economic evaluation of eucalypt energy plantations. *In*: Proc. Eucalyptus in California. Gen. Tech. Rept. PSW-69. USDA Forest Serv., Pacific Southwest Forest and Range Expt. Sta., Berkeley, Calif. pp. 42-48.

13. Stokes, B.J. and D.J. Frederick. 1986. Field trials of a short-rotation biomass feller buncher and selected harvesting systems. Biomass 11:185-204.

14. _________ and W.F. Watson. 1988. Flail processing: an emerging technology for the South. Paper 88-7527. Presented at the Inter. Winter Meeting of the Am. Soc. of Agri. Engineers. ASAE, St. Joseph, Mich.

15. Strauss, C.H. and L.L. Wright. 1990. Woody biomass production costs in the United States: an economic summary of commercial populus plantation systems. Paper presented at Institute of Gas Technology Conf. "Energy from Biomass and Wastes XIV." Inst. of Gas Tech., Lake Buena Vista, Fla.

16. Woodfin, S., D. Frederick, and B.Stokes. 1987. Selected harvesting machines for short rotation intensive culture biomass plantations. Presented at the Inter. Winter Meeting of the Am. Soc. of Agri. Engineers. ASAE, St. Joseph, Mich.